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Revision to
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Calibration, Quality Assurance, and Maintenance Program for Dosimetry Equipment and Selected Radiation Sources at AFRRI



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AFRRI Technical Report 96-4

**CALIBRATION, QUALITY ASSURANCE, AND
MAINTENANCE PROGRAM FOR
DOSIMETRY EQUIPMENT AND SELECTED
RADIATION SOURCES AT AFRRI**

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AFRRI Technical Report 96-4, a revision of AFRRI Technical Report 95-1, corrects the equation on page C-2 and the formula in enclosure (1) to appendix C. AFRRI Technical Report 95-1 should be removed from circulation.

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Introduction

The Operational Dosimetry Division of the Radiation Sciences Department at the Armed Forces Radiobiology Research Institute (AFRRI) maintains an in-house calibration, quality assurance, and maintenance program for dosimetry equipment and selected radiation sources. Calibration is traceable to the National Institute of Standards and Technology (NIST) through the MD Anderson Cancer Center (MDACC) in Houston, Tex. MDACC is an accredited dosimetry calibration laboratory whose measurement systems are calibrated annually by NIST.

Quality assurance and maintenance of equipment are closely related and consist of tracking equipment performance during normal usage and calibration, spotting problems early, and removing any suspect equipment from service as quickly as possible for repair or replacement. Quality assurance checks for the Cobalt Facility, Linear Accelerator (LINAC) Facility, and the Maxitron industrial x-ray machine in the Standards Laboratory are carried out through quarterly dose intercomparisons with MDACC. The Instrumentation Support Division of the Resource Management Department at AFRRI maintains an accredited calibration program and manages maintenance and repair of equipment.

Calibration

An ion chamber and an electrometer are sent to MDACC annually to be calibrated; calibration is thereby traceable to NIST. Currently, our standards are an Exradin air-equivalent ion chamber (Model A2; Lisle, Ill.) and a Keithley electrometer (Model 616; Cleveland, Ohio). Annual MDACC calibration consists of the following steps: an ion chamber and electrometer are first calibrated at AFRRI, sent to MDACC for calibration, and are recalibrated on return to AFRRI. All calibration results are compared to see if there have been any significant changes in responses while the equipment was out of AFRRI. Results must be within 2% of previous history. If comparisons are within the prescribed limit, the calibration factors obtained from MDACC are then used for calibration at AFRRI. The calibration factor for the NIST-traceable ion chamber is in units of roentgen per nanocoulomb (R/nC). Electrometers are calibrated by the Instrumentation Support Division of AFRRI's Resource Management Department in its high-voltage (HV) laboratory, using a precision HV power supply, a capacitor of accurately known capacitance, and a calibrated picoampere source. The picoampere source and our data acquisition/control units (DACU) are also calibrated by the Instrumentation Support Division. Electronic database files list the status and calibration factors for each ion chamber and electrometer.

Ion Chamber

Annual in-house calibration of an ion chamber is a fairly simple process. Calibration is performed using a ^{60}Co irradiator (Carter and Verrelli, 1973) and a new automated data collection and processing system recently installed on a dedicated personal computer (PC) at the Cobalt Facility (see appendix A for a discussion of this system and the testing performed to validate it). The code that is the center of the automated system is available on request. The MDACC-calibrated, NIST-traceable, air-equivalent ion chamber is placed in the cobalt field, and the exposure rate is determined. This value is used for the remaining calculations performed during the calibration of ion chambers. The ion chambers to be calibrated are then placed into the field, and data are taken and processed through the software on the dedicated PC to obtain the calibration factor for each ion chamber. The calibration factor, α for 0.5-cc ion chambers and N_{gas} for 0.05-cc ion chambers, is in units of centigray per nanocoulomb (cGy/nC). The protocol for calibrating ion chambers and the procedures in detail are provided in appendix B. Equipment setup for ion chamber calibration is shown in figure 1.

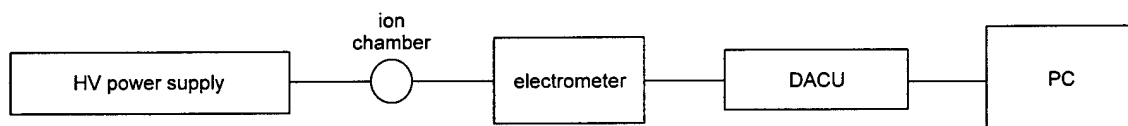


Fig. 1. Equipment setup for ion chamber calibration.

Electrometer

The calibration program for electrometers uses well-known physical relationships between capacitance, voltage, and current to determine the appropriate correction factors for each scale (ampere and coulomb) and each range within each scale used on electrometers.

The calibration of electrometers on the ampere scale is straightforward. A calibrated picoampere source is connected to the electrometer, and the current from the picoampere source is measured on each range within the ampere scale. A ratio is then taken of the expected response for each range over the actual response that was measured for that range. For example, if the expected response was 1.000×10^{-9} amperes, but the actual response was 0.986×10^{-9} amperes, then the ratio is 1.014. If both numbers were in agreement, then the value of the ratio would be 1.000. This ratio is the electrometer correction coefficient value k_e for each range. Using a particular range, all data taken are multiplied by the k_e for that range to obtain the true corrected reading before corrections for temperature, pressure, or any other factors are applied that might affect the data obtained from the electrometer. The equipment setup for calibrating electrometers on the ampere scale consists only of a picoampere source connected directly to the electrometer being calculated (due to the simplicity of the setup, there is no figure showing how the equipment is set up).

The calibration of electrometers on the coulomb scale is a little more involved. A calibrated HV power supply whose output is known for high precision, a capacitor for which the capacitance is precisely known, and the electrometer in question are connected in series so that the voltage from the HV power supply is put through the capacitor, which sends a signal to the electrometer. The voltage levels to be applied should be chosen so that the voltage combined with the capacitance of the capacitor yield an expected unit response at each range in the coulomb scale of the electrometer, i.e., an expected response of 1.000×10^{-9} coulombs. The relationship between voltage, capacitance, and charge is governed by the equation

$$Q = CV$$

where

Q = expected charge yielded by the interaction of the applied high voltage and the capacitance of the capacitor in coulombs,

C = capacitance of the capacitor in farads, and

V = applied voltage in volts.

Next, a ratio of the expected response for each range over the actual response for that range is taken. This ratio is the k_e for that range. The equipment setup for the calibration of electrometers on the coulomb scale is shown in figure 2. The protocol for the calibration of electrometers is provided in appendix C.

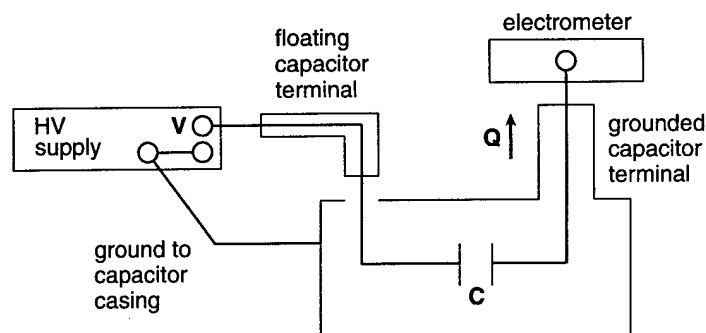


Fig. 2. Equipment setup for calibrating electrometers on the coulomb scale.

Quality Assurance and Maintenance

Quality assurance and maintenance of the in-house program are closely related. There are frequent opportunities to detect faulty equipment and remove equipment for repair. The performance of ion chambers and electrometers is routinely checked at the start of each dosimetry session with capacitance checks. Performance is also monitored during dosimetry and during experiments by default—any fault in the equipment quickly becomes apparent.

Quality of equipment performance is also checked at each annual calibration. For electrometers, this is straightforward. The k_e 's are checked to see that they are as close to 1.000 as required by internal standards. Any value for k_e that is significantly different (2%) than 1.000 indicates at the very least that there is something wrong with the electrometer range that yields the anomalous result. A problem with the range being calibrated can also be detected by a sudden and significant shift in the value of k_e for the range in question. To determine what constitutes an anomalous or significantly different result is a matter of training, experience, and judgement. As a rule of thumb, however, any change greater than 2% in any measured or tracked parameter is considered adequate reason to remove a piece of equipment from service for troubleshooting. For ion chambers, each time a chamber is calibrated, a value, N_x , is found as one of the steps for calculating N_{gas} and α . The ratio of the new N_x over the average of the previous values of N_x is calculated. The new value must be within 2% of the average of the previous values; otherwise, the chamber is removed from service for troubleshooting and possible repair. Further, when a chamber is new or is returned from repair, it is calibrated to check its performance before its use. While the calibration factors for new and repaired chambers cannot be compared with previous data, the calibration process will catch any obvious problem. To distinguish between a "good" calibration factor and a "bad" calibration factor depends on experience, judgement, and a general knowledge of the sort of response that is expected from a given type, size, and make of ion chamber.

Records of performance are kept in two places, depending on when the performance was checked. For performance checks during calibrations, records are kept in the calibration binder and notebooks and are also maintained in electronic database files. The database files are records not only of equipment performance but also of maintenance histories of various pieces of equipment. For checks

on performance during dosimetry and experiment monitoring, various quantities are observed, and some are tracked to check equipment performance. On the operational side of quality assurance, performance checks are more a matter of continuous observation of equipment performance rather than formal tracking of performance characteristics. The quantities that are tracked vary from source to source, and binders kept for each source should be checked to see what quantities are currently being tracked. Examples of the quantities being tracked at the time of writing this report are the monitor factors for ion chambers at all sources, the ratio of counts from the fission counters over reactor power, and the ion recombination correction factor p_{ion} for ion chambers at the LINAC.

Quality Assurance for Radiation Sources

Quality assurance is also maintained for the LINAC, Cobalt Facility, and the Maxitron x-ray machine through thermoluminescent dosimeter (TLD) intercomparisons with MDACC. We receive TLDs from MDACC on a quarterly basis. The TLDs received are a photon TLD for the Cobalt Facility, a photon TLD for the Maxitron, and two photon TLDs and two electron TLDs for the LINAC. We deliver a specific dose to the TLDs for each source and send them back to MDACC to be read. The results are sent back to AFRRI, and the dose delivered as determined by reading the TLDs is compared to the dose we stated that we delivered to the TLDs. If the two results compare to within 5%, then the intercomparison is acceptable. Otherwise, steps are taken to determine the source of the difference and to correct it. We have also used Fricke dosimeters from NIST for quality assurance at the Cobalt Facility and the LINAC, but due to erratic results obtained from the dosimeters and their high cost, this quality check was discontinued.

Conclusion

AFRRI's in-house calibration, quality assurance, and maintenance program is a dynamic program whose goal is to ensure that dosimetry support is consistently of the highest caliber. The program is continually growing and changing, standards are revised as necessary, and tracking of quantities that are not indicative of performance are replaced with tracking of quantities that are indicative of performance. The quantities tracked for the purpose of quality assurance vary from source to source because different quantities have significance for quality assurance at different sources. The only common quantities tracked at different sources at this writing are monitor factors.

In addition to value tracking, there are a number of untracked items that will also indicate whether or not there is a problem with a piece of equipment. These items include capacitance checks, dosimetry, and monitoring of equipment performance during experiments. The significance of these untracked items and when these items indicate a problem are a matter of training, experience, and judgement. Judgement calls are always made conservatively: if there is any doubt as to whether a piece of equipment is working properly, it is taken out of service and thoroughly checked before it is used again.

Finally, all ion chambers and electrometers, whether or not they are used regularly, are checked for problems annually during their calibrations. During this process, performance is checked against past performance to maintain consistency. Other factors, such as the physical condition of the equipment, are checked to see that they are acceptable. Records of equipment performance are maintained in the various source quality assurance binders, calibration binders and notebooks, and in electronic database files.

Reference

Carter, R. E., and Verrelli, D. M. AFRRI Cobalt Whole-Body Irradiator. Technical Note TN 73-3, Armed Forces Radiobiology Research Institute, Bethesda, Maryland, 1973.

Acknowledgement

The authors wish to express our appreciation to Betty Ann Torres for the initial information in starting this project and to Gregory Johnson for his many hours of help with software testing.

Appendices

TESTING AND VALIDATION OF NEW ION CHAMBER CALIBRATION SYSTEM

When calibrating ion chambers, data were originally taken using a Hewlett Packard (HP) 85 computer (Corvallis, Oregon), and all calculations were done manually. There were two major drawbacks with this system. First, there was a good chance that errors could occur because several stages of calculations had to be made, and correction factors were therefore applied at each stage. Second, these calculations took a significant amount of time and reduced the number of calibrations that could be done in a given day. Quite often the final calculations were done as time permitted and, if a chamber needed recalibration, it had to be done on another day—a considerable length of time could pass before the next opportunity presented itself.

In late 1992, the first improvement to the calibration system was made by creating an Enable spreadsheet (Enable Software, Inc., Ballston Lake, New York) to automate calculations, to reduce the chance of calculational and systematic errors, and to provide immediate results. The use of the spreadsheet increased the number of calibrations that could be done in 1 day, and chambers could be recalibrated immediately if necessary. Even with this improved system, there were still potential problems. Data were still being manually entered into the spreadsheet. Again, there was the potential for error in entering data. While faster than the old system, it was still not as fast as a system that would integrate data collection, analysis, and processing into a fully automated package with a much lower chance of error. The object of this report is to document and validate just such an automated software package.

Calibration System

The calibration system consists of a Zenith 248 computer (St. Joseph, Michigan; comparable to an 80286 IBM-AT class PC) with a National Instruments General Purpose Interface Bus (GPIB) card (NI-488.2; Austin, Texas), interfaced to a Data Acquisition/Control Unit (HP3421A DACU; Hewlett Packard (Corvallis, Oregon), which reads signals from a Keithley 616 Digital Electrometer (Cleveland, Ohio). The electrometer was calibrated at MDACC in Houston, Texas, and is traceable to NIST. The calibration program (ION6.BAS) was written for Microsoft (MS-DOS; Redmond, Washington) in Basic using Microsoft QuickBASIC, Version 4.5, and National Instruments NI-488.2 MS-DOS/Windows Handler for the AT-GPIB communications software (version 2.1). During development, the system was tested using a picoampere source instead of exposing an ion chamber to a radiation field. Since Keithley no longer manufactures model 616 electrometers, it is likely that the present electrometer will be replaced with a Keithley 617 electrometer. In any case, any electrometer in place of the Keithley 616 electrometer has to cover scales from 10^{-9} to 10^{-7} coulombs, have a coaxial or triaxial input jack, and must have receptacles for banana plugs for connection to the DACU.

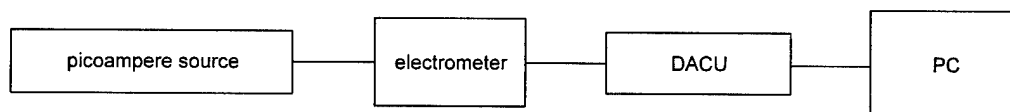


Fig. 1. Equipment setup for tests using a picoampere source.

Figure 1 shows the equipment setup for the tests using the picoampere source, and figure 2 shows the equipment setup for ion chamber calibrations.

The following constants are embedded in the code for the calibration software and are traceable to the Task Group 21 Protocol of the American Association of Physicists in Medicine:

F = conversion factor from R to cGy for 0.05-cc ion chambers = 0.836 cGy/R

k_{wall} = wall correction factor for attenuating the radiation beam within the wall and surrounding buildup material of the ion chamber :

0.05-cc chamber 0.981 for 4-mm buildup cap
 0.978 for 6-mm buildup cap

0.50-cc chamber 0.988 for tissue-equivalent chambers, 4-mm buildup cap
 0.989 for magnesium chambers, 1-mm buildup cap

50.0-cc chamber 0.977 for tissue-equivalent chambers
 0.978 for graphite chambers

f_{med} = conversion factor from R to cGy for 0.50-cc and 50.0-cc ion chambers =
 0.966 cGy/R

Measurements and Methods

To validate the new software system we tested both systems using a wide range of measurement scales and electrometer correction coefficient values (k_e) that are much different than $k_e = 1.0$. The tests simulated situations that are unlike those expected during normal calibrations. The tests culminated in calibrating our standard air-equivalent ion chamber (AE 146) using both the new and old systems and comparing the results. AE 146 is our standard chamber because both it and the

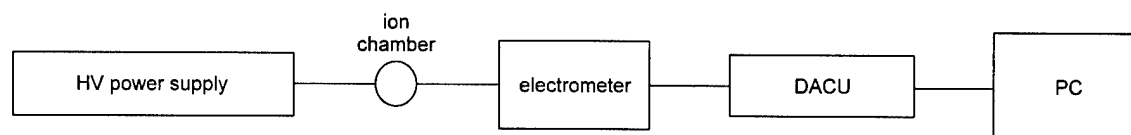


Fig. 2. Standard equipment setup for calibrating an ion chamber.

electrometer used in ion chamber calibrations have been calibrated at MDACC. Two categories of tests and a calibration were performed:

- Using a picoampere source, we tested both systems on the 10^{-7} , 10^{-8} , 10^{-9} , and 10^{-10} scales, with the scales matching on both the picoampere source and the electrometer.
- Setting the picoampere source and the electrometer on the E-9 scale, we used k_e values 0.5 and 2.0, which are much different than $k_e = 1.0$.
- After completing the above tests, we calibrated the ion chamber AE 146 according to the Protocol for the Calibration of Ion Chambers, General Dosimetry (GD) Protocol 94-03 (GD-94-03) and compared the results of the two systems.

Results

Table 1 compares the responses of the two systems as the picoampere source and electrometer scales were varied. Table 2 shows the results of the tests involving k_e values that are much different than 1.0. The tests varying the k_e values were done with the electrometer on the 10^{-9} coulomb scale, and the output from the picoampere source was 1×10^{-9} amperes. Table 3 provides the results for both systems from the actual calibration of the standard ion chamber AE 146. Table 4 provides the results of a quick final test of the new system after a minor modification was made to allow its use in AFRRI's ^{60}Co whole-body irradiator. This modification deleted a procedure that automatically calculated the decay-corrected exposure rate given by the Theratron-80 (Atomic Energy of Canada, Ltd.) in the Standards Laboratory and added a menu item to the code that allows the exposure rate to be entered manually each time a calibration is performed. The exposure rate at the ^{60}Co Facility is determined each day using the standard ion chamber AE 146 before calibration starts.

Quantities in the following four tables are defined as follows: ΔQ , amount of charge collected in coulombs in a specified period of time; N_x , calibration factor of the ion chamber, expressed in R/nC; α , calibration factor of the ion chamber, modified by a correction factor to convert exposure in air to dose in a medium (in this case, tissue), expressed in cGy/nC; and k_e , electrometer correction factor derived from calibrating the electrometer and used to correct the reading from the electrometer to the actual charge collected.

Table 1. Comparison of the results of current output and electrometer scales for the old and new systems.

Scale		System		Ratio of old to new	System		Ratio of old to new	System		Ratio of old to new
Pico-ampere source	Electro-meter	Old $\Delta Q/\text{min}$	New $\Delta Q/\text{min}$		Old N_x	New N_x		Old α	New α	
1×10^{-7}	10^{-7}	60.560	60.481	1.0013	.6353	.6361	0.9987	0.6064	0.6071	0.9988
1×10^{-8}	10^{-8}	60.293	60.231	1.0010	.6484	.6490	0.9991	0.6188	0.6195	0.9989
1×10^{-9}	10^{-9}	60.747	60.711	1.0006	.6501	.6504	0.9995	0.6204	0.6208	0.9994
1×10^{-10}	10^{-10}	59.709	59.565	1.0024	.6500	.6515	0.9977	0.6203	0.6219	0.9974

Table 2. Comparison of the results of using k_e 's that are much different than the 1.0 k_e for the old and new systems.

k_e	System		Ratio of old to new	System		Ratio of old to new	System		Ratio of old to new
	Old $\Delta Q/\text{min}$	New $\Delta Q/\text{min}$		Old N_x	New N_x		Old α	New α	
2.0	6.1070	6.0835	1.0039	3.1902	3.2025	0.9962	3.0448	3.0565	0.9962
0.5	6.1025	6.0867	1.0026	12.7702	12.8034	0.9974	12.1880	12.2197	0.9974

Table 3. Comparison of the results of the calibration of the standard ion chamber AE 146 using both systems.

System		Ratio of old to new	System		Ratio of old to new
Old $\Delta Q/\text{min}$	New $\Delta Q/\text{min}$		Old N_x	New N_x	
6.4179	6.4389	0.9967	6.1575	6.1374	1.0033

Table 4. Results of final comparison of both systems.

Scale		System		Ratio of old to new	System		Ratio of old to new	System		Ratio of old to new
Pico-ampere source	Electro-meter	Old $\Delta Q/\text{min}$	New $\Delta Q/\text{min}$		Old N_x	New N_x		Old α	New α	
1×10^{-10}	10^{-10}	60.73	60.47	1.0043	0.6497	0.6526	0.9956	0.6201	0.6229	0.9956

Conclusion

After all tests were done, the greatest difference between the responses of the old and new systems was 0.44%. These results validate the new software system for calibrating ion chambers and allow transition from the old calibration system to the newer, more accurate and efficient system.

CALIBRATION OF AN ION CHAMBER

1. Equipment Required

- Chamber to be calibrated
- PC with GWBASIC and ION6 computer code ION6.BAS
- High voltage (HV) power supply
- Data acquisition and control unit (DACU)
- Standard air-equivalent ion chamber AE 146 and electrometer with NIST-traceable calibrations

2. Calibration. Exact procedures depend on the reason for calibration: annual chamber check, new or newly repaired chamber, or checkout of a defective chamber. Whatever the reason, equipment is always set up as in figure 1.

a. Software. The software package used for calibrations is a GWBASIC program called ION6. The menu-driven program provides the steps involved in calibrating an ion chamber. The program is in the ION directory and is accessed by typing ION6 followed by a space and *.dat. The file *.dat is automatically created to save the collected data, and the asterisk is the chamber to be calibrated. For example, to calibrate ion chamber TE 324, type the filename "ION6 te324.dat" to access the program. After each calibration, exit the program, and restart it with a new filename to save data for calibrating the next ion chamber.

(1) To initialize the program, you are asked to enter the AFRRI number of the electrometer being used, the data channel to be read, the scale to be used (should be E-9 coulombs), and the time interval between data collections, which should be 10 seconds. Channel 4 is the standard channel used for calibrations, but only for consistency's sake. If something goes wrong with channel 4, you may change to another channel. Just make sure that you initialize the program to read the correct channel.

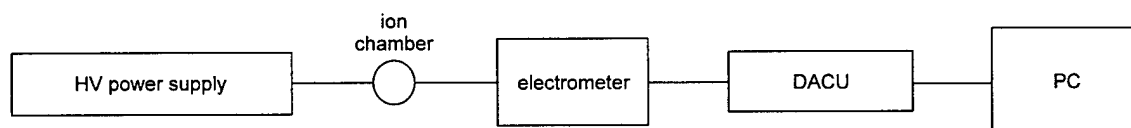


Fig. 1. Equipment setup for calibrating an ion chamber.

(2) To find the k_{tp} , you are asked to enter the temperature and pressure, and the computer then calculates the k_{tp} .

Data are automatically collected into two buffers, positive and negative, depending on the polarity of the HV power supply. The program will collect 13 data points for each buffer, discarding the first data point for purposes of data averaging. Simply press P to start collecting data into the positive buffer and N to start collecting data into the negative buffer. From here on, the process is completely automated. Data are averaged, and calculations are performed by simply choosing options from the menu. The electrometer calibration factor k_e must be entered at the ion calibration factor (N_x) calculation stage. The program performs the calculations for all types of chambers that could possibly be undergoing calibration. At the end of the analysis, simply find the listing for the chamber that you actually calibrated, and record the appropriate calibration factor. Due to the constants embedded in the code, it is important to note that the calibration factor for any chamber type other than the one you actually calibrated is then wrong. DO NOT use any calibration factor for any chamber type other than the type that was actually calibrated. If calibrating a 0.05-cc TE chamber, DO NOT use a calculated calibration factor for a 0.5-cc or 50.0-cc chamber. A copy of the code and an example of the output are provided in the enclosure to this protocol. Enter the exposure rate determined by the procedures in the paragraph that follows. Then proceed with the last two items on the program menu to obtain the calibration factor for the ion chamber in question.

b. Exposure Rate. Place the AE 146 air-equivalent ion chamber into the ^{60}Co field being used for calibration, and determine the exposure rate. The active volume of the chamber should be centered on the table, using the existing markings, at a height of 32.3 cm above the table. This is best accomplished by using the stand that the ^{60}Co Facility uses for its ion chamber, which is positioned in its standard dosimetry position as marked on the table, with the active volume of the chamber centered on the centerlines marked on the table. The calibration factor for the AE 146 ion chamber is in units of roentgen per coulomb (R/C). To find the exposure rate, use the following equation:

$$R/\text{min} = (N_x)(10^{-9} \text{ C/nC})(Q/t)(k_{tp})(k_e) \quad (1)$$

where

N_x = calibration factor of AE 146 in R/C,

10^{-9}C/nC = conversion of coulombs to nanocoulombs
(10^{-9} coulombs per nanocoulomb),

Q = total charge collected in nC,

t = total time elapsed in minutes during exposure,

k_e = electrometer correction factor, and

k_{tp} = temperature and pressure correction factor.

Use the data acquisition routine in the software, and take full data sets at both positive and negative polarity. Set the data acquisition interval at 10 seconds. Add the last twelve Q s for each polarity (24 Q s in all), and use this number in equation (1) above to calculate the exposure rate. In this case, $t = 4$ minutes.

c. Calibration. The various procedures used in the calibration of ion chambers are provided below. Table 1 in paragraph 2c(5) provides procedures to be used under specified circumstances. In all cases the chamber is to be centered in the radiation field.

(1) Capacitance check. Start with the electrometer on zero check and the HV power supply set to zero volts output. When high voltage is applied, take the electrometer off zero check, and wait several seconds to see that the electrometer stabilizes. Apply voltage in increments of +100 V up to the operating voltage of the chamber being calibrated (+400 V for 0.5-cc chambers, +500 V for 0.05-cc chambers). Wait for the reading to appear on the computer screen before proceeding to the next voltage level. Check to see that the measured charge differences, ΔQ s, are self-consistent to within 2%; do this by taking the ratio of the highest ΔQ to the lowest ΔQ to see if they are within 2% of each other. The ΔQ s are the accumulated charge over a 10-second time frame. It is possible, though rare, to have a percentage difference greater than 2%. If this should occur, repeat the capacitance check, and recheck self-consistency. Sometimes transient phenomena appear and then disappear with a second capacitance check. Percentage differences up to 2% are acceptable for proceeding with the calibration, but be alert for problems later on in the calibration process. There probably won't be any, but it is possible that self-consistencies with greater than 2% differences could indicate a problem with the chamber. If there isn't a good capacitance check in three tries, remove the chamber, and mark it for repair.

(2) Capacitance calculation. After obtaining a satisfactory capacitance check, average the ΔQ s obtained, and use this average to calculate the capacitance of the chamber with the following equation:

$$F = [(\Delta Q_{\text{avg}})(k_e)(k_{tp})/\Delta V] \quad (2)$$

where

F = capacitance in farads,

ΔQ_{avg} = average of ΔQ s in coulombs from capacitance checks,

k_e = electrometer correction factor,

k_{tp} = temperature and pressure correction factor, and

ΔV = voltage increment in volts.

Record the value of the capacitance on the log sheet, and plot it on the quality assurance chart for the chamber being calibrated. Compare it with the average of previous values. It should not vary from this average by more than 2%. If it does, remove it for repair, and move on to the next chamber. The average of previously calculated capacitances should not include any values listed previously with a notation of trouble or repair. An example of the calculation of capacitance is provided in the enclosure to this protocol.

(3) Detailed gas-flow check. This check ensures that the chamber cavity is completely filled with gas and is responding correctly. First, expose the chamber to the radiation field with no gas flowing through it. Using the computer, collect a full set of data at positive polarity, average the data, and record the ΔQ s. Then connect the gas supply to the ion chamber, and turn the gas on. Fully open the gas-flow valve on the flow meter, and flush the chamber for 10 minutes. Decrease the gas flow to the normal flow rate used for the ion chamber being calibrated, expose the chamber to the calibration field, take a full set of data at positive polarity, average the ΔQ s, and record the average ΔQ . Again fully open the gas-flow valve, and flush the chamber for another 10 minutes. Once again, reduce the gas flow to normal levels, and take another full data set at positive polarity, average the ΔQ s, and record the average ΔQ . Repeat the flushing procedure again, collect and average another full data set, and record the average ΔQ . If the individual average ΔQ s do not compare to within 2% to 3% of the mean of the averages of the ΔQ s, remove the chamber, and send it out for repair. Also, watch for signs of an upward or downward trend in the average ΔQ s. If this happens after three flushing cycles, remove the chamber, and send it out for repair.

(4) Saturation check. Take data on the response of the chamber in +100-V increments from +100 V to +500 V. Take five ΔQ s at each voltage level, and average them as ΔQ . Make a plot of $1/\Delta Q$ along the abscissa versus $1/V$ where V is the voltage level at each ΔQ . Find the Y intercept, and normalize to the $1/\Delta Q$ at +400 V. This ratio is the k_{sat} , ion chamber saturation correction factor. The value for k_{sat} should be within 0.5% of 1.000. If it is not, one of two things must be done: for ion chambers that operate at +400 V or +500 V, remove the ion chamber from service for repair; for ion chambers that operate above +500 V, repeat the procedure given above, but this time, start at +200 V and work up to +100 V to +200 V above the normal operating voltage for the ion chamber being calibrated in +200-V increments. Plot the data as above, except normalize the Y intercept to $1/\Delta Q$ at the operating voltage of the ion chamber in question. The VAX program, RS1, is very helpful in plotting data. Simply input all data, and fit a curve to them.

(5) Calibration. Using the software, collect a complete data set at positive polarity on the HV power supply, switch polarity to negative, and collect a second complete set of data at negative polarity. Again using the program, average and process the data to obtain calibration factors for the chambers. When collecting data into the buffers, wait a few seconds after the field has come "on," or when polarity has been switched, to begin collecting data into the buffers of opposite polarity. Waiting gives the system a chance to stabilize before data collection begins. If for some reason you start data collection and the system is not yet stabilized (i.e., there are significant fluctuations in the ΔQ s being measured), restart data collection for the buffer you are currently working with. After you have collected and averaged the data, use the computer to calculate the calibration factor N_x , and print a report of the calibration. Printing the report outputs the report to the monitor. To print the actual file (i.e., TE324.DAT), the file must be copied to a disk and inserted into a computer connected to a printer. The data file will not actually be created until you choose "Print File" (item 7) from the menu. Also, when finished calibrating a chamber, exit the program (item 8 on the menu), and re-initialize using a new filename if another chamber is to be calibrated. The calibration factor N_x is in units of R/C and is converted to cGy/nC by a conversion factor embedded in the program. These constants are discussed in paragraph 2g. The final calibration factor is defined as N_{gas} for 0.05-cc ion chambers, and as α for 0.50-cc and 50.0-cc ion chambers. The formula for the calibration factor and the various factors that go into its calculation are

$$N_x = (X)/[(\Delta Q_{avg}/min)(k_e)(k_{tp})] \quad (3)$$

where

N_x = calibration factor in R/C,

X = exposure rate in R/min,

$\Delta Q_{avg}/min$ = the average amount of charge collected in a minute, as calculated by the code in nC/min,

k_e = electrometer correction factor, and

k_{tp} = temperature and pressure correction factor.

The conversion of N_x to a calibration factor expressed as cGy/nC is carried out according to the following equation:

$$N_{gas} \text{ or } \alpha = (N_x)(F \text{ or } f_{med})(k_{wall}) \quad (4)$$

where

N_{gas} or α = calibration factor as defined above,

F or f_{med} = conversion factor, R/C to cGy/nC, defined in paragraph 2g, and

k_{wall} = wall correction factor, defined in paragraph 2g.

Table 1. Ion chamber (IC) calibration procedures.

Type of IC calibration	Capacitance check	Capacitance calculation	Detailed gas flow check	Saturation check	Calibration
New 0.5 cc	X	X	X	X	X
Repaired 0.5 cc	X	X	X	X	X
Annual 0.5 cc	X	X	X*		X
New 0.05 cc	X	X		X	X
Repaired 0.05 cc	X	X		X	X
Annual 0.05 cc	X	X			X

*For a modified gas-flow check, check only two points. Do not collect data for the chamber with no gas flowing through it.

Note: Table columns are arranged in order of procedures to be done. When calibrating a chamber, start at the left, work across the table to the right, and perform the procedures with an X in the column.

d. Quality Assurance. QA charts for the chamber capacitance and value of N_x for each chamber must be maintained and updated as appropriate. Maintain a separate chart for each chamber in the Ion Chamber Calibration Binder.

e. Documentation. Generate a hard copy report of each file created during calibration, and place it in the Ion Chamber Calibration Laboratory Notebook. Electronic copies of each file go into the C:\IONCAL directory. Update the Paradox database file ioncal.pdx with the calibration factor, date of calibration, capacitance, and any applicable notes for each chamber calibrated. Print a hard copy of the database file, and place it in the Ion Chamber Calibration Binder and in the LINAC and reactor QA notebooks, as appropriate.

f. Recalibration. Ion chambers are to be recalibrated annually. Also, when a new ion chamber is received or comes back from repair, it must be calibrated before it is put into service. Finally, circumstances can arise that call for calibration of an ion chamber for special uses or to check its performance as part of troubleshooting.

g. Embedded Constants. The following constants are embedded in the code of the calibration program for the purposes of calculating the calibration factors for ion chambers:

F = conversion factor from R to cGy, in air 0.05-cc ion chamber = 0.836 cGy/R

k_{wall} = wall correction factor for different thicknesses of buildup caps (buildup material)

0.05-cc chambers	0.981 cGy/R for 4-mm buildup cap 0.978 cGy/R for 6-mm buildup cap
------------------	--

0.50-cc chambers	0.988 cGy/R for tissue-equivalent chambers 0.989 cGy/R for magnesium chambers
------------------	--

50.0-cc chambers	0.977 cGy/R for tissue-equivalent chambers 0.978 cGy/R for graphite chambers
------------------	---

f_{med} = conversion factor from R to cGy in the wall medium for 0.50-cc and 50.0-cc ion chambers = 0.966 cGy/R

The constants listed above are given in the TG-21 protocol. It should be noted that these constants are valid only for a ^{60}Co field. Different constants would apply to other sources.

h. Notebook Reference. The memorandum of record regarding the software system change-over can be found in notebook BRP-11B, page 30. Calculations performed by the calibration computer program are based on the TG-21 protocol.

EXAMPLE OF CALCULATING THE CAPACITANCE OF AN ION CHAMBER

Assume $k_{tp} = 1.017$
 $k_e = 0.986$

$\Delta Q_s = 0.07361 \text{ E-9 C}$
 0.07259 E-9 C
 0.07412 E-9 C
 0.07349 E-9 C

$\Delta V = 100 \text{ V}$

To calculate the chamber's capacitance, first average the ΔQ_s . The average ΔQ is 0.07345 E-9 C . Applying equation (2) and inserting the appropriate values,

$$C = [(\Delta Q_{avg})(k_e)(k_{tp})/\Delta V] = [(0.07345 \text{ E-9 C})(0.986)(1.017)/100 \text{ V}] = 7.37 \text{ E-13 F.}$$

CALIBRATION OF AN ELECTROMETER AND CALCULATION OF THE ELECTROMETER CALIBRATION CORRECTION FACTOR k_e

1. Equipment Required

- Calibrated picoampere source
- 1,000-pF capacitor with accuracy at least 0.1%
- High voltage (HV) power supply with accuracy at least 0.1%, located in the HV laboratory in LOGI
- Electrometer(s) to be calibrated

2. Calibration

a. Setup. Set up electrometers on the calibration bench in LOGI, turn them on, and let them warm up for at least 1 hour before starting calibration. This is very important because if electrometers are not allowed enough time to stabilize, calibration data will be worthless.

(1) Ampere scale. Connect the picoampere source and electrometer in series. It is all right to connect an electrometer before it is warmed up, but do not calibrate it before it has warmed up. Equipment setup is simple; no figure is provided.

(2) Coulomb scale. Connect the HV power supply, the capacitor, and the first electrometer to be calibrated in series, as shown in figure 1. It is all right to connect an electrometer before it has warmed up, but do not calibrate it before it has warmed up.

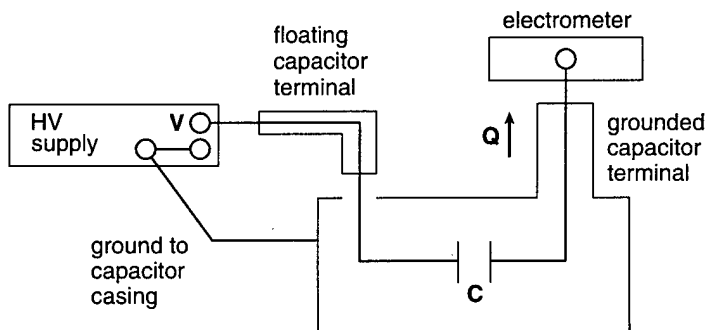


Fig. 1. Equipment setup using the coulomb scale for calibration.

b. Calibration

(1) Ampere scale, E-7 to E-10 amperes. For each range within this scale, use the picoampere source to send a signal of unit current to the electrometer. For the 1 E-7 range, choose E-7 amperes from the picoampere source, E-8 amperes for the 1 E-8 range, etc. Record the actual and expected readings from the electrometer. The k_e for these ranges will be the ratio of the expected response over the actual response. Use enclosure (1) as a guide for recording the data.

(2) Coulomb scale. For each scale on the electrometer, set the voltage on the HV power supply at the level indicated in table 1. Use enclosure (2) as a guide for recording the response of the electrometer. For one voltage level for each electrometer (it does not matter which voltage level you pick), check the response of the electrometer with the HV power supply set at negative polarity, and compare it with the response at positive polarity. The two responses should not vary by more than 4%. Any big difference in the responses indicates a possible problem with the electrometer, and LOGI must check it. The voltages given in table 1 in conjunction with the 1000-pF capacitor will theoretically produce 1 E-7, 1 E-8, 1 E-9, and 1 E-10 coulombs, respectively, as determined by the equation

$$\Delta Q = CV \quad (1)$$

where

C = capacitance, and

ΔV = voltage step.

The electrometer calibration correction factor is a ratio of the expected theoretical electrometer response to the actual measured electrometer response. To find k_e , use the following equation:

$$k_e = \Delta Q_e / \Delta Q_m \quad (2)$$

where

ΔQ_e = expected electrometer response, and

ΔQ_m = actual electrometer response.

Calculate the k_e for each electrometer scale, and record it on the calibration form for the coulomb scale (enclosure (2)).

Table 1. Voltage levels for electrometer scale settings for calibration.

Scale	Voltage level
1 E-7 C	+100
1 E-8 C	+10
1 E-9 C	+1
1 E-10 C	+.1

c. Documentation. Generate reports for reactor and LINAC k_e 's. File a copy of each report in the Electrometer Calibrations Laboratory Notebook (BRP-30), a copy of reactor k_e 's in the Reactor Quality Assurance Binder, and a copy of LINAC k_e 's in the LINAC Quality Assurance Binder.

d. Recalibration. Electrometers must be recalibrated annually.

e. Notebook Reference. The early calibrations are recorded in notebook BRP-30.

ELECTROMETER CALIBRATION: AMPERE SCALE

Name _____ Date _____ Electrometer _____

Input (A)	Reading (A)	k_e

$k_e = \text{Input/Reading}$

Signature _____

Recalibrate by _____ (date).

ELECTROMETER CALIBRATION TABLE: COULOMB SCALE

Name _____ Date _____ Electrometer _____

[illegible]

Equations: $\Delta Q = C\Delta V = Rk_e$; $k_e = \Delta Q/R$

Signature _____

Recalibrate by _____ (date).

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